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One of the most important sanitary problems associated with the digging of the Panama Canal is that of the suppression of mosquito-borne diseases.

This may be accomplished in a variety of ways, but it is the purpose of this paper to describe one only—that of culicidal fumigation.

The sanitary department has carried out an enormous number of fumigations on a large scale, affording opportunities for the study of this branch of public hygiene, which have probably never been excelled. This paper is based largely upon results obtained during this work.

As the work progressed several problems arose whose solution could not be found in the literature available. This work was taken up by the laboratory of the board of health, and as many of the results are new they have been incorporated here.

This paper will be divided into several sections, as follows:

1. Method of procedure in fumigating.
2. Factors influencing the results of fumigation.
3. Various fumigants in common use, their properties and method of use.
4. Experimental fumigations.
5. New apparatus.
6. Summary and conclusions.

METHOD OF PROCEDURE.

A brief description of the usual procedure carried out in the fumigations in Panama will not only illustrate the methods employed, but will make clear many points which will be discussed later on.

Fumigation consists of three steps—preparation of the house, actual fumigation, and cleaning up after the process is complete.

The house to be fumigated has all the openings closed up by means of manila paper, or some similar material. Large openings are frequently closed by heavy canvas, particularly if there is much wind; paper is apt to tear under such conditions. Small openings, cracks, etc., are closed with strips of newspaper of sufficient width to allow a considerable overlapping on all sides of the hole, so that the paper will adhere well when pasted. Tacks are usually employed on the larger openings, as well as paste.

The principal precaution to be observed in preparing the house, aside from stopping up all the openings, is to disturb as little as possible whatever insects, particularly mosquitoes, may be within. It is

customary to enter thru one door only, which is protected by a curtain of heavy canvas to prevent the escape of insects.

After the house is pasted up (which takes from one to several hours, depending upon the size and condition of the edifice), the pots containing the fumigant are brought in; the amount of fumigant used in each pot and each compartment depends upon the size and shape of the area to be fumigated. As a rule, 2 pounds of sulfur or pyrethrum, the two most commonly used culicides, are allowed to each thousand cubic feet, and not more than 4 pounds are placed in a pot. This amount is chosen for several reasons; with smaller amounts per pot and a larger number of pots combustion is much quicker and usually more complete; a large amount of the culicidal substance is introduced in a comparatively short time, and the loss by leakage, unless it is excessive, is met by the large volume of fumes which is generated in a minimal space of time. The sulfur or pyrethrum is lighted by methyl alcohol; a small amount is placed in each pot, in a small crater-shaped hollow made in the fumigant; this lights readily and starts the slower burning sulfur without trouble.

The time consumed in fumigating is usually about two or three hours. This allows ample time for the sulfur or pyrethrum to burn, and permits the fumes to diffuse thoroly thruout the building. At the expiration of the time allowed for the actual fumigation the house is opened, the mosquitoes swept up with a damp broom, the paper and paste removed, and the house is once more ready for occupation.

FACTORS INFLUENCING THE RESULTS OF FUMIGATION.

Loss of active fumigating substance occurs by leakage, absorption, and condensation. Diffusion plays a very important part in the success of the operation as well.

The penetration of a culicidal agent, considered apart from its diffusibility, is practically of no importance. Mosquitoes can not penetrate the substance of fabrics or other furnishings, consequently, if the fumes diffuse sufficiently to envelop every article in the space which is being fumigated, the insects are almost certain to be affected. As a rule mosquitoes, as well as many other insects, show a remarkable tendency to hide in cracks and crevices where there is more or less intimate contact with the fresh uncontaminated air where the culicidal action is minimal. This is particularly the case with old houses in the Tropics, which are built for the maximum amount of ventilation, and where openings are not only not harmful but actually beneficial in so far as they facilitate the free entrance of air. Such edifices are extremely difficult to close tightly, and in such places one must use a culicide which has great killing powers.

As a rule, fortunately, structures presenting difficulties of this sort contain little or nothing which is actually damaged by sulfur dioxide, and it is customary to use sulfur under these conditions.

The presence of large amounts of furniture, draperies, and hangings in general, which present a large amount of surface in proportion to the space actually occupied, as well as offering hiding places for insects, seriously affect the results of fumigation. Not only is there loss of culicidal action due to poor diffusion, but the condensation of fumes on the surface of such fixtures results in further loss. Ordinarily there is a certain amount of loss from this factor (condensation),

which increases as the room departs from a rectangular shape. The presence of excessive amounts of fixtures, however, greatly increases the loss, with a resulting diminution in the efficiency of the fumigation.

Wind causes considerable trouble at times. It is not at all infrequent to see clouds of fumes on the leeward side of a house when the breeze is strong, particularly houses having tiled or corrugated metal roofs. In certain instances mosquitoes on the upper floor of a house where there is no false ceiling are alive at the close of the fumigation, whereas those on the lower floor are all dead. This may occur even if the lower story is relatively open, provided the upper floors alone are exposed to the action of the wind. If there are stairways leading from the lower to the upper floors the suction may be sufficient to draw up considerable quantities of fumes, so that there will be hardly any escape of smoke when the house is opened. So many observations of this kind have been made here that we feel quite confident in attributing the loss to the action of the wind rather than to the fact that the fumes have a different specific gravity than that of the air. Buildings having false ceilings are as a rule free from this loss. It has been found possible to eliminate the condition practically by hanging heavy canvas in such a manner as to break up the air currents. The same rule holds for large buildings. If the doors are closed, making each room a unit by itself, the results are usually better than if the doors are left open, giving a free sweep to the air currents, which have a tendency to concentrate the fumes on one side of the building to the detriment of the remaining portion. Since air currents are usually associated with leaks, there may be actual loss of active culicidal substance.

Moisture is a very unimportant factor, altho the relative humidity is usually sufficient in Panama, so there would have been comparatively little trouble from this source even had it been essential.

VARIOUS FUMIGANTS, THEIR PROPERTIES, AND METHODS OF USE.

These substances will be taken up in order of their relative culicidal values.

Sulfur is without doubt the best practical culicide known at the present time, so far as actual fumigation is concerned. It is cheap, effective, easy to manipulate, even with the unskilled labor available on the Isthmus, bears transportation well, undergoes no change, even if kept for a long time and except from small amounts of earthy impurities is not sophisticated. It can be obtained in almost unlimited quantities and is available in any place. Relatively small amounts of this substance will successfully fumigate large areas.

Rosenau, in his excellent book, *Disinfection and Disinfectants*, has summarized the disadvantages of this substance. He says:

"It bleaches all coloring matters of vegetable origin and many anilin dyes, and attacks almost all metals. It acts upon cotton and linen fabrics so as to seriously weaken their tensile strength."

We have found that it quickly discolors paint, both fresh and old.

Moisture does not seem to be desirable for sulfur fumigation.

Theoretically, 1 pound of sulfur burned completely in 1,000 cubic feet of space, provided the room is tightly closed, should produce 1.15

per cent of the gas. Leakage and impurities in the substance materially lower this amount, so that the actual per cent is less than 1. It seems to be a fairly conservative estimate to assume that 2 pounds per 1,000 cubic feet, the amount usually used here, will give about $1\frac{3}{4}$ per cent of the gas. This is amply sufficient, however, to kill mosquitoes and most other insects.

Sulfur dioxide is evolved comparatively slowly from the solid sulfur, hence it is necessary to have the rooms which are to be fumigated tightly closed. Generally speaking, it is much better to burn sulfur in relatively small amounts per pot and use more pots. As a rule not more than 4 pounds should be used in each pot where the leakage is likely to be excessive; by so doing and using a large number of pots much more sulfur is evolved in a unit of time, and the volume of gas neutralizes to a certain extent the losses due to leakage. Sulfur is best and most cheaply burned in iron pots. A convenient size is about 18 inches in diameter and 6 inches deep. Such pots are supported on legs in such a manner that the floor of the pot shall be about 4 inches above the ground. Larger pots, about 2 feet in diameter, are placed beneath the sulfur pots and are filled with water or moist sand. This is done to prevent accidents. It not infrequently happens that a pot will crack, the melted sulfur runs out of the crack, and if there were no pot beneath there would be grave danger of fire. As it is the sulfur burns on the sand or is extinguished in the water. In either case this danger is reduced to a minimum. It is customary to place a thin layer of pyrethrum in each pot before the sulfur is put in. This serves to protect the bottom of the pot from the corrosive action of the melted sulfur and makes cleaning much easier. The melted sulfur, if it is not all consumed, adheres strongly to the iron and is extremely difficult to remove.

Sulfur kills practically every known domestic insect, and is an excellent destructor of rats, mice, and vermin in general.

Pyrethrum is the only other culicide which has been used on a practical scale in Panama. It is variously known as pyrethrum, Buhach, Persian insect powder, and Dalmation powder. It occurs in trade in three forms, or rather three grades, altho the retailers do not, as a rule, mention this fact. The first grade is made from nonexpanded flowers, the second of expanded flowers, while the third grade is prepared by grinding up small stems, twigs, and leaves, together with tumeric to give the mixture color, and a small amount of the better grade to furnish the necessary aroma. Adulterations are common. One of the best known is camel's dung. Various other substances are used, the particular material varying with the place in which the pyrethrum is prepared.

The unexpanded flowers, the first grade, furnishes a fairly efficient culicide, but the second and third grades are practically inert. Mosquitoes are either killed or stupefied when exposed to the fumes of good pyrethrum for a sufficiently long time. Hence it is necessary to sweep up a room which has been fumigated with this substance with a damp broom as soon as possible and burn the mosquitoes. Even then there is danger of missing some of the insects.

The powder itself has culicidal properties. Kalbrunner has devised a "household" test for a good grade of pyrethrum. According to this investigator 4 grains of pyrethrum sprinkled on a fly in a small closed space, such as a bottle, should kill, or at least stupefy it in one

minute. This does not form a very valuable index to the culicidal properties in actual fumigation, and it is much better to actually burn some of the sample as will be described later on, and observe the effect.

The United States Army Regulations call for 5 pounds of pyrethrum per 1,000 cubic feet in culicidal fumigation; it has been customary to use two or three in a similar space here.

Pyrethrum rapidly loses its culicidal value if freely exposed to the air. Several experiments carried on here seem to show that even the best grades will become inert in less than five weeks if no provision is made to keep the powder dry and tightly sealed.

This substance is used precisely the same as sulfur. It is placed in the same kind of pots and ignited in the same manner. Usually it takes from two to three hours for the complete combustion of 4 pounds of pyrethrum when burned by the pot method. It is not advisable to use more than this amount if there is an excessive leakage in a house, for the same reason that small amounts in each pot and a large number of pots were used with sulfur, namely, that the rapid production of fumes equalizes to a certain extent losses by leakage.

Perhaps the greatest source of danger, both with sulfur and pyrethrum fumigations is the free flame that of necessity accompanies this method of fumigation. To be sure, the flame rarely rises more than a few inches above the top of the pot except when the substance is first lighted and the alcohol is blazing, but there is an element of danger which it would be well to eliminate if possible. At the present time there seems to be no good way of doing this; if the pot is made deep the supply of oxygen is diminished, which will result in poor combustion, with sulfur at least.

A new culicidal agent, variously known as Minn's mixture, campho-phenique, camphor, and carbolic acid, has been tried with a certain amount of success in the United States, particularly during the last year. Various observers have found great differences in its behavior, and up to the present time it can hardly be said to be an efficient culicide. Doctor Berry, of the Marine-Hospital Service, reported favorably on its use, and he found that the mixture could be volatilized in a tin pan placed upon the top of a short piece of stovepipe. The great trouble is said to have been the danger of the mixture catching fire. The camphor will burn in such a case with an intensely smoky flame, covering everything with a layer of soot which is difficult to remove. Berry used this substance, however, with considerable success, and a large number of experiments have been made here using special apparatus, which will be described in detail later on in this paper.

Campho-phenique consists of a mixture of equal weights of camphor and 95 per cent carbolic acid. It is made by dissolving camphor in carbolic acid of the strength mentioned, using 2 ounces of camphor and 2 ounces of the acid ordinarily to each thousand feet of space to be fumigated. The camphor dissolves with considerable readiness, forming a solution which occupies almost twice the volume occupied by the acid. This is remarkable, a substance dissolved in another substance forming a resulting solution of twice the original volume. The solution is usually rather milky at first, due largely to the inclusion of air bubbles during the process of stirring; but it soon clears up, particularly if it is heated, forming a light yellow fluid. It is extremely oily, and unpleasant to handle because of its strong corrosive action on the hands or other parts upon which it may be spilled. Fortunately

one always has alcohol in which to bathe the affected part, because alcohol lamps are used as the source of heat when this substance is volatilized.

The vapor of campho-phenique, which is the active culicidal substance evolved, has a rather pungent odor, in which both the camphor and carbolic acid may be recognized. The laborers here prefer to enter a house fumigated with this substance rather than one in which sulfur is used. The only untoward result that has come to our notice is bloody urine, and this has happened in only one case. Undoubtedly more cases would have occurred had there been any considerable fumigation carried on in which this substance was used.

The camphor mixture is placed in shallow pans, in the quantities mentioned above, and subjected to the heat of an alcohol lamp. The fumes come off in clouds, accompanied by the characteristic odor. The great advantages of this substance are its cheapness compared with pyrethrum, the fact that it may be generated quickly, taking rather less than an hour as compared with sulfur and pyrethrum, which require from two to three hours for their combustion, and the fact that it is harmless in its action, depositing neither soot nor injuring the finest fabrics, and the fact that its odor disappears very quickly after the house is opened up.

Herein lies its great advantage. It is customary to use pyrethrum where sulfur would do damage to furnishings, or, in general, in houses of the better class. Such houses are almost invariably well constructed, and consequently easy to close up tightly. Under these conditions, a substance which is about one-half as expensive as pyrethrum, which takes about one-third the time necessary to fumigate, and which will almost certainly kill mosquitoes, is a distinct advantage. We have made a large series of experiments, using campho-phenique, sulfur, and pyrethrum in three houses, situated precisely the same with regard to physical conditions, size, exposure, etc., and in each experiment we have succeeded in killing mosquitoes with the sulfur and camphor mixture, which in each experiment with one exception, the pyrethrum has failed to come up to this result. Full details of these experiments will shortly be made.

Hydrocyanic acid has been used successfully in nurseries, green-houses and warehouses where there is no danger to human life from the excessively poisonous fumes. Because of its chemical nature, it is quite out of the question to use it where the labor is as unskilled as is the case here.

Chlorine gas has been used to a limited extent, but its powerful bleaching action prohibits its use on a practical scale.

Carbon bisulphide is a fairly good culicide, but its inflammability makes its use dangerous.

Jimson weed or Stramonium has been proposed by Taylor, but experiments carried on here do not seem to indicate that this substance will prove of value. It is quite possible, however, that the material available was not of good quality, and that loss of active culicidal substance had occurred.

Formaldehyde, while an excellent bactericidal agent, is of practically no value as an insecticide unless used in large amounts in well-closed rooms. This is rather surprising, and furnishes practically the only example we have of a good bactericide being a very poor insecticide.

Doctor Francis, of the Marine-Hospital Service, has recently made

some interesting experiments with a substance called commercially "Pyrofum." This product seems to be closely related to pyroligneous acid, and is said to be cheap and efficient, the cost being about that of sulfur. The fumes are inflammable, and unless some method can be devised to overcome this difficulty it is doubtful if it can be used in practise. We have had no opportunity to try this substance here.

Many other substances having a greater or lesser insecticidal action have been proposed from time to time. Celli in his book on malaria mentions quite a number. He divided them into three groups, those producing odors, fumes, and gases, respectively. He made a number of observations upon the action of these substances, but the methods employed were of such a nature as to make their practical value questionable. Many of them are expensive, and the majority are unfamiliar to the laity.

EXPERIMENTAL FUMIGATION.

This portion of the work may conveniently be divided into three parts: (a) Control of actual practical fumigations by means of mosquitoes suitably placed in buildings during fumigation; (b) experimental fumigations in which every step is carefully controlled, and where every precaution is taken to insure uniform conditions; (c) methods of testing the culicidal value of fumigants from relatively small samples, such as are sent by manufacturers previous to purchase.

Before discussing this work it will be well to describe in detail the methods employed.

It is obviously impractical to fully determine the culicidal value of a fumigation by observing merely the condition of the mosquitoes and other insects that may be found when the process is completed. One can not count on finding insects in every room, and it is a laborious and time-consuming task to search for insects in the many out-of-the-way places in which they may be hidden and where they may have found protection, partial or complete, from the action of the fumes. It is easier and more accurate to arrange mosquitoes in such a manner that they shall have the maximum chance of escaping death and yet have them freely exposed to the fumes in so far as the latter could reach them. Such insects should be confined so that they may be easily found at the close of the fumigation.

If insects are inclosed in wire cages small enough to fit easily into any ordinary hiding place of a mosquito, yet large enough not to injure the insects by pressure, this end may be accomplished. We have used wire cages, made in the shape of a cylinder, 6 inches long and $1\frac{1}{2}$ inches in diameter, made of 20-mesh wire netting. The fineness of the mesh is necessary because of the fact that *Stegomyia fasciata*, particularly the smaller individuals, will pass thru a 16-mesh netting if the conditions are right.

These cages are closed at one end by wire netting of the same mesh and at the other with a wooden plug after the mosquitoes are introduced. Such pieces of apparatus permit the free passage of fumes, yet keep the mosquito in check. There is plenty of room so that the insect is not crowded, and the cages of a size such that they may be introduced in almost any portion of the room where mosquitoes might have a chance to survive the fumigation. It has been customary to so place these cages that the insects have the maximum chances for survival—under paper, next to cracks and similar openings which have

been prepared, but thru which there is bound to be a certain gaseous exchange with the outside, behind pictures, in rolls of various fabrics, in partially open drawers, and in the corners of rooms where by consequence of poor diffusion the fumes are less dense.

Not less than ten mosquitoes are placed in a cage, and *Anopheles*, *Stegomyia*, and *Culex*, the three common genera here, are used indiscriminately. At the close of the experiment the mosquitoes are removed and examined as soon as possible and any live ones noted. After twenty-four hours they are again examined, and if there have been no signs of life the experiment is regarded as successful. It is not unusual, particularly if the fumigant used is pyrethrum, to find a number of insects, apparently dead when removed from the house, flying around in the cages. This is due to the fact that such mosquitoes have simply been stupefied and have revived.

Those experiments in which one or more insects in a cage survive are marked unsatisfactory. We take the stand that the fumigation is intended to kill, and failure to do this, if the insects are so placed that they are freely exposed to the fumes, indicates that something was wrong. Under such conditions harm might easily be done. The inhabitants of the building acquire a sense of false security and omit the usual precautions which they otherwise would take.

The experimental investigations of culicids were undertaken because we could find nowhere in the literature a complete discussion of the relative values of these substances. Isolated observations have been made from time to time, but they were unsatisfactory. They can not be translated in terms of sulfur, pyrethrum, etc., and be sure that the conclusions which would naturally be drawn would be justifiable.

In order to do this sort of work properly it is necessary to have houses of such a size that the values obtained will be fulfilled in practise, and so situated that the various agents tested shall be under the same physical conditions. Mention of the various factors disturbing fumigations on a practical scale has already been made above.

Fortunately there are three houses on the north slope of Ancon Hill, removed from any human habitation, which fulfil the desired conditions very satisfactorily. These houses are amply separated from one another to eliminate all physical conditions which might occur, such as protection from wind, rain, or sun, and yet near enough together so that a minimal amount of travel is necessary to go from one to another.

They are built upon the same plan and have the following dimensions: 28 feet long, 28 feet wide, 14 feet high to the beginning of the roof timbers, and 8 feet from this point to the ridgepole. The roof slopes symmetrically from a height of 22 feet above the floor. The roof is of corrugated metal, overlapt on each layer of iron about 3 inches. While this form of roof is practically rain-tight, fumes can to a certain extent leak out between the different layers of metal plates, forming loss which amounts to considerable if there is much wind. Inasmuch as many of the buildings which have been fumigated on the Isthmus are of this same construction this defect is an advantage rather than otherwise for experimental purposes.

The houses are divided into four equal parts by two partitions running at right angles, with doors in each room allowing communication with adjacent rooms. These partitions reach to the beginning of the roof timbers, 14 feet above the floor, but above this there is no partition, merely an open space 28 feet square, bounded by the roof.

Inasmuch as these houses are exactly alike in every respect and at the same time are large enough to furnish a very practical space for fumigation (14,112 cubic feet) the conditions are ideal for side-by-side comparison of various culicids, and the results presented here were invariably obtained in these houses unless otherwise specified.

A gang of five men was constantly employed to keep the place in order and to perform the manual operations attendant upon fumigation, pasting, cleaning up, arranging the pots, removing pots when the fumigation was ended, and, in general, in carrying out those procedures which are necessary for successful fumigation.

In order to save time all the openings were pasted up and, with the exception of two doors diametrically opposite one another, permanently closed. These two doors were left to permit free entrance and to facilitate the escape of fumes after the operation was completed. Two doors opposite one another would of course make a draft thru the building and soon remove all odors, etc. Only one experiment was made each day. By so doing the houses were fresh and free from all fumes for the next experiment. Sundays no fumigation was attempted, and the houses had one extra day's airing.

Papering was done more thoroly than was usually the case in regular fumigations. The paper was put on double and reenforced with strips of tape to prevent tearing off the covering by the wind. Actual tightness, however, was hardly greater than that obtained in any house, because experiments have shown that the manila paper, when it is whole, is practically impervious to the escape of fumes. At first no attempt was made to paper the joints formed by the overlapping roof plates, but it was found that whenever a high wind was blowing this was absolutely essential. Several experiments were tried, each of which was successful if the roof was papered; unsuccessful if the roof was not papered. This was true, however, only when there was considerable breeze. Experiment No. 58, carried out in Panama, illustrates the same point in practical fumigation.

Pots were placed away from the corners of the rooms to prevent accidental fires which might occur thru the ignition of the woodwork of the house. The pots were placed in larger pots, which in turn were filled with moist sand to prevent accidents in case the upper pots containing the culicid leaked. During the progress of the fumigation watchmen were always stationed in places where they could see the houses and guard against fires.

Mosquitoes for this investigation were reared from larvæ and pupæ sent in from along the line or collected by inspectors in Panama. They were of course free from infection. The larvæ or pupæ were placed in a screened house 6 by 6 by 6 feet, with a vestibule 4 by 4 by 6 feet. The floor was of cement, with four depressions, 24 by 10 by 6 inches, in each of which was a layer of mud, some algæ, and about 4 inches of water. The *Spirogyra* has been found to be an excellent food for many mosquitoes.

After the mosquitoes leave the pupal stage they fly up onto the screened sides and may be removed with ease from this position. Not infrequently several thousand mosquitoes have been flying around this box at one time. They are fed upon ripe bananas, altho many obtain blood when one enters to catch them. We have been unable to see any difference in resistance between those fed upon blood or those who have eaten vegetable matter so far as fumigation is concerned.

The mosquitoes were caught directly in the wire cages described above and placed in the houses as soon as possible, always retaining a certain number as controls. It sometimes happened that the mosquitoes were weakened by long residence in this wire house, as was shown by the death of several in the cages before the fumigation actually began. Under such conditions it was of course necessary to obtain a fresh supply before going on with the experiment. After considerable experimenting the following locations were selected as furnishing insects with the maximum chance for survival during the fumigation: The four corners of the house, both on the floor and at the level of the roof rafters; a point 14 feet above the floor in the center of the building, and over the windows. Mosquitoes were always placed in these positions in each house so that the exposure, as far as it is possible to control it, was the same in every case. As a rule from nine to fifteen tubes were placed in the house; the insects chosen indiscriminately from the mosquito-breeding house, and there could have been no chance of error in this direction.

As soon as possible after the house was opened at the close of the fumigation the mosquitoes were removed and placed in the fresh air. After a short interval they were examined, and any tubes showing live insects carefully marked. The rest were kept for twenty-four hours and again examined. It not infrequently happens that live insects are found at this time when they were apparently dead immediately after the fumigation. In such instances the culicide merely stupefied them and they revived. Hence the need of this precaution.

Whenever pyrethrum or sulfur was used care was taken to use approximately the same amount of alcohol to light each pot. In experiments carried out on a small scale it was noticed that the temperature went up to over 50° C., if much alcohol was used, altho this elevated temperature was transient and lasted only a few minutes. At the same time it often happened that the mosquitoes were seriously injured by even a short exposure to this amount of heat. In no instance did the temperature run above 43° C. in any of the experimental fumigations, altho in small houses it was not infrequently 50° C. in the Panama fumigations.

The accompanying tables show the results as well as the comparisons of fumigations in Panama with pyrethrum, sulfur, and camphorphenique, and experimental fumigations. The direct comparison of the three above-mentioned culicides forms a table by itself. The remaining tables show results obtained in actual practise, and dual comparisons using varying amounts of each of the fumigants. The experiments in Panama represent results that may be expected in routine work. They were made as opportunity offered, with no intention of choosing more or less favorable houses. The rather poor results found in certain cases may excite comment, but as a result, in part, at least, of this work yellow fever has disappeared from the Canal Zone, and there has been no recurrence of this disease.

DESCRIPTION OF FUMIGATION TABLES.

For convenience the tables showing results of pyrethrum and sulfur fumigations are divided into two parts, the first portion indicating in tabular form the practical fumigations as they actually occurred, the last the experimental results where every possible precaution was taken to insure the uniformity of conditions.

Before discussing the tables in great detail, it will be well to make a few specific statements relative to the practical use of sulfur and pyrethrum, altho this point has been discusst largely in a general manner above. Sulfur is used in those houses where there has been grave infection, or in structures where there is little or nothing which would be damaged by its corrosive fumes. Pyrethrum, on the other hand, altho much inferior to sulfur as an insecticide, is used in houses with costly hangings, fine furniture, and expensive decorations. The use of pyrethrum is always attended with more or less uncertainty. Rosenau (loc. cit.) has summarized in his usual terse manner the value of this culicide.

It is used either as a dry powder or by its burning fumes. As a dry powder it may be used pure or mixt with flour, in which form it should be puffed about the room, especially into cracks. Against mosquitos the powder should be burned in the room, and if used in sufficient strength and for a sufficient length of time it will kill many of these insects, but it can not be depended upon for the destruction of mosquitoes infected with yellow fever, for some of the insects are merely stupefied. They must be destroyed after the fumigation.

The regulations of the United States Army require the burning of 5 pounds of pyrethrum for each 1,000 cubic feet of air space for the destruction of mosquitoes in confined spaces.

To be absolutely exact in discussing the practical results obtained with sulfur and pyrethrum would necessitate a detailed description of each and every fumigation upon which observations were made. This is impracticable, and only those cases which bring out some important point will be mentioned in detail. To facilitate description, a set of abbreviations have been used in the tables—the terms “old” and “new” applied to buildings indicate not so much the actual age per se, but rather the condition of the structures with regard to their tightness. In general by the term “new” is meant a building which is well constructed, with few places from which the fumes could escape, aside from legitimate openings such as doors and windows, while an “old” building is one in which there are many cracks and crevices leading to the outside. In case the latter are excessive the term is amplified in a suitable manner.

Well-papered houses or houses tightly closed are those in which all objectionable openings have been well closed by paper or heavy canvas in such a manner as to preclude the escape of fumes.

RESULTS IN DETAIL.

Sulfur (Table I).—Experiments beginning at No. 11 and ending with No. 70, inclusive, in this table were obtained by placing mosquitoes in tubes as previously described in various houses immediately before lighting the sulfur. The houses were chosen at random. No attempt was made to pick out especially favorable or unfavorable houses for this work, and no warning was given to the fumigating squad prior to the event.

Experiments Nos. 11, 12, 13, and 14 were augmented by placing rats suitably confined in rat cages in various locations within the houses. In each case it will be noted that the results of the fumigation both from the point of view of destruction of rats and mosquitoes were excellent.

Experiment No. 19 was carried out in a very old house of large size. There were many cracks to be closed, but this was well done.

After the house was opened, not only were the mosquitoes killed, but many cockroaches and other vermin were found dead upon the floors.

Experiment No. 16 represents one of a class, fortunately small, in which excellent results were expected. The house was well papered, the pots well placed, but the results were unsatisfactory. All the sulfur was burned, and no suitable explanation for the result can be given.

Experiment No. 58 is an excellent example of the effect of wind upon houses with no false ceiling and with corrugated metal roofs. The roof is rain but not air tight, and it was found that mosquitoes placed upon the top floor were all alive, while those on the ground floor were dead. There was evidently a draft produced by the passing of the wind over the roof, which created sufficient suction to remove a very considerable portion of the sulfur fumes. A trapdoor which was closed at the head of the stairway prevented the loss of fumes from the lower floor.

Experiments Nos. 18 to 125, inclusive, were carried out in the houses mentioned above and show in general the efficiency of sulfur as a culicide. Experiments Nos. 67 and 68 were disappointing, altho small amounts of sulfur were used—1 pound per 1,000 cubic feet. These experiments were repeated later with better results. (See experiments Nos. 80 to 125, inclusive.) The failure to obtain perfect results in the first instance and the excellent results obtained later on are due to the better knowledge of the proper distribution of pots, as well as increased skill upon the part of the men who did the manual labor for this work. This point is of some importance in any fumigation. It is found by experience that those houses fumigated later in the work give uniformly better results than those first fumigated.

In the experimental fumigations in which every factor was controlled (Nos. 18 to 125), two general problems were studied—the effect of using a small number of pots with a relatively large amount of sulfur per pot, and a large number of pots with a relatively small amount of sulfur per pot. The amounts of fumigant per 1,000 cubic feet were also varied in both series.

The uniformly good results obtained by both methods do not of themselves give any definite indications of the relative value of the two procedures, but from observations made during the practical fumigations it is safe to say that, aside from minimizing the danger of one or more pots not burning, the plan of using a larger number of pots with a smaller amount of sulfur per pot is the better way, particularly if there is much leakage. The rapid generation of sulfur fumes neutralizes the loss which thus occurs.

Under favorable conditions as small an amount as 1 pound per pot could be used (with 1 pound per 1,000 cubic feet) with good chances of success. The reduction in time necessary for complete combustion is considerable. In three instances the time has been cut down to one hour, but in practise one rarely meets with conditions sufficiently good to allow one to make this reduction.

Pyrethrum (Table II).—The results obtained with pyrethrum are on the whole unsatisfactory, altho they confirm the observations made by Rosenau and others. Of the twelve practical experiments (Nos. 8 to 64) only two gave perfect results. The remainder were extremely poor, altho the houses were quite as well papered as those in which sulfur was used. The general results of this work as well as the character of the houses are shown in this table.

In the experimental fumigations, Nos. 21 to 126 inclusive, the same results were obtained. Of the twenty-four trials three gave perfect results, four more gave good results, while the remainder were unsatisfactory. Various lots of pyrethrum, barreled and in tins, new and old, were used, and while the fresh-tinned pyrethrum was the most effective of all, yet the use of this culicide is attended with grave doubts as to its value, and the only conclusions one can draw are that it is of little value for culicidal fumigation.

Campho-phenique (Table III).—This substance, first used in the Gulf States, has been tried with great success here. Several observers have not succeeded in killing mosquitoes in a satisfactory manner, and the results here, using their methods, have been equally unsatisfactory. Not only were insects frequently found alive at the end of the fumigation, but grave doubts were entertained as to its value practically, because of the reported inflammable nature of the camphor.

Berry, of the Marine-Hospital Service, experimenting with this mixture, found that a shallow pan placed upon a short piece of stove-pipe formed a good apparatus for volatilizing the campho-phenique, and his method was tried here. The results were disappointing, and, except for a fortunate trial of the fumes of this substance, they would have been discontinued. It was observed that the fumes killed mosquitoes with great rapidity, and that the insects were actually dead, not merely stupefied, as is the case with pyrethrum. With this observation as a basis, a piece of apparatus, which will be described in great detail later on, was evolved which has given excellent results in our hands.

The apparatus was constructed with the idea of removing every possible source of danger which could occur with this mixture, as well as to provide for the fact that unskilled labor would have to be employed in practical fumigations. Cheapness is the first consideration, because it is frequently necessary to use large numbers of pots in fumigating large buildings. The use of galvanized-sheet iron, which is comparatively inexpensive, not only reduces this factor, but makes the apparatus light and not easily broken.

To provide for the notorious lack of skill shown by the native workmen, steps have been taken to make it absolutely necessary for the apparatus to be set up correctly. It is practically impossible to make it work in any other way than the correct one. Each and every part must occupy its correct relation to every other part, and of necessity this must be carried out in order to evolve fumes.

In order to prevent any possible accident due to the catching fire of the camphor, a special fumigating pan has been constructed. This pan is circular in shape, with the edges turned downward and outward, making a total diameter of 7 inches. In section it is concave, so that in reality it is a shallow bowl having a diameter greater than that of the stand upon which it is supported, with the edges turned down at an angle of 45° with the perpendicular. This shaped pan is especially adapted to the evaporation of any liquid; the concavity causes the last remaining portions of liquid to remain in the center of the apparatus, where it is exposed to the hottest part of the flame, and the convexity presented to the flame permits the maximum effect of the latter for evaporation. Inasmuch as it is made of galvanized iron, hammered out of one piece, there are no joints to leak, solder to melt, and the form is eminently suited for stacking a large number one inside the other for transportation.

The stand is of galvanized iron, riveted into a cylindrical shape, 6 inches in diameter and $5\frac{1}{2}$ inches high. Near the top is a row of holes thru which the hot air from the lamp escapes, forming a natural draft. This hot air acts upon the campho-phenique that may be near the edge of the pan, away from the direct action of the flame, causing rapid evaporation at this point as well as in the center of the pan, which sets into the top of the stand. The stand is supported upon three iron legs 2 inches long in the clear, which is turned outward at right angles at the bottom one half inch. This is done so that they may fit into appropriate straps in the bottom of the safety pan, in which the stand sets, to assure the correct placing of the latter.

The safety pan is also made of galvanized iron 11 inches in diameter. In the bottom are three straps into which the "turned-out" part of the legs of the stand fit. In the center of the safety pan there is a ring one-half inch high, 3 inches in diameter, into which the alcohol lamp fits. With the stand confined in its proper place by the straps, the lamp likewise placed in its ring, it will be seen that there is no possibility of any portion of the apparatus occupying an incorrect position. The safety pan not only holds the stand in position, but when half filled with water forms an effective protection in case the alcohol lamp should begin to leak. Any lateral spurting of alcohol is prevented by the sides of the stand, and the excess alcohol would immediately be extinguished by the water.

It should be mentioned in passing that the ledge which is turned down on the fumigating pan is to prevent the flame of the alcohol lamp passing over the edge of the pan, and thus setting fire to the camphor and carbolic acid.

To summarize:

We have an apparatus consisting of four parts, a fumigating pan, designed to evaporate campho-phenique, formaldehyde, or other similar liquid, with an especially molded edge designed to prevent contact of the liquid with the free flame, and to concentrate the fluid as it is evaporated in such a manner that the last portions shall be distilled off.

The stand is designed for steadiness, protection of the flame from drafts, and to give rigidity to the evaporating (fumigating) pan.

The safety pan is intended to support in their proper relations both the stand with its pan and the lamp which supplies the heat for evaporation, as well as a safeguard against leakage of the lamp.

The lamp found to give the best flame, everything considered, is No. 15 metal spirit lamp manufactured by Whitall, Tatum & Co.

The whole apparatus is made as cheaply, durably, and easy of transportation as possible. It is so constructed as to permit its use by unskilled labor, with the minimal chance for damage both to itself and to the house or other structure in which it may be used.

The fumigating pan will hold 8 ounces of campho-phenique when made in the dimensions given, namely, $6\frac{1}{2}$ inches in diameter exclusive of the overhanging edge, and $1\frac{1}{2}$ inches in depth in the center. With the alcohol lamp one-third full, ample time is given for complete evaporation of the liquid, with about five minutes to spare to allow for conditions which slow down the rate of evaporation.

Table III gives the results of our experimental investigations with this substance, and it will be seen that aside from the first two experiments which were made with the "pan-stove pipe" method the culi-

cide effect has been excellent. In order to compare pyrethrum, sulfur, and campho-phenique side by side, in houses of exactly the same construction, and under the same conditions, a series of comparative trials have been made. Table IV shows the results obtained, and it will be noted that under the given conditions (a fairly tight house, with corrugated metal roof, tightly papered in each case) the campho-phenique and sulfur have given practically perfect results. Four ounces of the camphor-carbolic acid mixture and sulfur in amounts varying from 1 to 3 pounds per 1,000 cubic feet have been used. In several instances considerable leakage, due to the wind passing over the metal roof carrying off fumes have occurred, but even when small leaks of known size have been made purposely no change in the results have occurred. We feel justified in saying that campho-phenique in moderately well built, tight houses will give as good results as sulfur, and considering the extra time needed for sulfur fumigation, at an equal, or more probably, a lesser cost.

In order to test the action of the three culicides upon fruit a series of two experiments have been made under the same conditions. Bananas, quite ripe, mangoes, and oranges have been used in these experiments. The mosquitoes were not only placed in the customary positions in the houses, but were also carefully hidden as much as possible in the bunches of bananas to simulate conditions which would occur on shipboard. The results (Table V) show that campho-phenique is less harmful than sulfur or pyrethrum to the fruit. There was very little darkening of the skins of the bananas or other fruit when exposed to this substance, and the bananas did not taste. Several observers made these observations simultaneously, and the results herein described are those which were obtained after tasting the fruit before and after fumigation, and also by carefully preserved controls. The bananas were unfortunately a little too ripe to make the conditions exactly as they should have been, but the indications are that the campho-phenique is less harmful than the sulfur. Pyrethrum did not kill the mosquitoes, and is not considered suitable for this work. With the campho-phenique the insects were killed in every case; in the first trial, where the time was only three-quarters of an hour, one mosquito which was situated near the roof, where the fumes were practically removed by the action of the wind, survived for nearly half an hour, altho it could not walk or fly. In thirty minutes it was dead. This was the only survivor of about eighty insects placed in the building at that time. The mosquitoes hidden in the fruit were all killed. It is interesting to note that the first experiment, carried out in a strong breeze, also resulted in a larger number of survivals of mosquitoes in the house fumigated by sulfur, and that they, too, were near the roof, where there was loss of fumes, due to wind action.

Before summarizing this paper, mention should be made of the apparently small number of perfect practical fumigations. It would seem at first sight that the survival of mosquitoes in houses which have been fumigated would be accompanied by fresh outbreaks of yellow fever or other mosquito-borne disease. Doctor Carter, director of hospitals, has summarized this situation up in concrete example. Fumigation is in any event efficient in proportion to the number of early cases discovered and the efficiency of the fumigant in killing mosquitoes. Fumigation is more or less objectionable to the inhabit-

ants of the infected area; more objectionable as the fumigant employed damages furnishings or decorating, and as it leaves unpleasant odors or residues, and less objectionable as these factors, as well as the time consumed, are decreased.

Of two fumigants, one of which is perfect from the point of view of killing mosquitoes, but injuring fabrics and furnishings, the other 80 per cent as efficient, but much less distasteful to the inhabitants, the following theoretical case would obtain: With the objectionable fumigant as many as possible of the inhabitants would conceal cases, so that say 20 per cent only were discovered and fumigated during the infective period of the disease. This would give an efficiency of 20 per cent mosquitoes killed, because the method is perfect.

On the other hand, employing the less objectionable fumigant, say 50 per cent of the cases would be fumigated within the required time. Then the percentage would be 80 per cent of 50 per cent, or 40 per cent as the final removal of infected and infective mosquitoes. This means that the less objectionable fumigant, altho it does not kill every mosquito in the infected houses, gives finally a better result than the first fumigant.

Sulfur is decidedly objectionable in many ways; it kills mosquitoes, however, and may be looked upon as a nearly perfect fumigant for these insects. Pyrethrum, if it were more efficient, would do very well, altho it leaves a decided coloration on light colored paint, and is objectionable from the point of view of time consumed in fumigation, three or more hours being necessary, as a rule, for its combustion.

Campho-phenique in well-furnished houses (which in the vast majority of cases are also well-constructed) is very much less objectionable than either of the above, and it combines this factor with the comparatively short time necessary for its evaporation, and the fact that it leaves a very slight residual odor, which quickly disappears, so that the houses are comfortably habitable as soon as the cleaning up process is complete. In such cases it has given quite as good results as sulfur, and, considering everything, is much the cheapest fumigant of the three.

SUMMARY AND CONCLUSION.

1. Campho-phenique in well-constructed houses is a cheap, efficient, and nonobjectionable culicide, possessing, particularly when combined with formaldehyde, good bacterial properties as well.

2. Sulfur is an excellent culicide, but is injurious to fine fittings and fabrics.

3. Pyrethrum is not a reliable culicide, and causes darkening of light-colored paint and similar substances.

4. The apparatus herein described has given excellent results with the campho-phenique, while all other appliances have failed entirely in this respect.

5. All three culicides have a certain effect on fruits, altho the campho-phenique was less injurious than either of the others.

6. Certain physical factors, wind, leakage, large connected rooms in which no precautions are taken to break up the air currents, as well as surface condensation affect seriously the results of fumigation, and should be considered in detail when undertaking culicidal destruction.

In conclusion the writer desires to express the debt he owes to Col. W. C. Gorgas, chief sanitary officer, who has had the apparatus con-

structed for this work, and who has personally supervised certain of the experiments; to Major Carter, who has given much valuable advice and attention to this work; Dr. John Purnell, health officer of Panama, who has provided both men and material, as well as overlooking many of the results, and the members of the fumigating squad who have faithfully carried out the details of the experiments.

TABLE I.—*Sulfur.*

Experiment No.	Fumigant used per 1,000 cubic feet.	Area fumigated.	Fumigant used.	Time.	Mosquitoes.			Remarks.
					Number.	Dead.	Alive.	
	<i>Lbs.</i>	<i>Cu. ft.</i>	<i>Lbs.</i>	<i>Hrs.</i>				
11	2.00	44,000	88	2½	8	8	0	Tight house; 1 rat and 2 mice killed.
12	2.00	48,000	96	3	10	10	0	Tight house; 6 mice killed.
13	2.00	8,000	16	3	3	3	0	Tight house; 1 mouse killed.
14	2.00	48,000	96	3	5	5	0	Tight house.
16	2.00	23,832	47	3	10	2	8	Old house, fairly tight.
17	2.00	42,000	84	2½	10	10	0	Tight house.
19	2.00	97,160	194	3	20	20	0	Large house, fairly tight; cockroaches killed.
24	2.00	41,791	83	2	20	20	0	Tight house.
28	2.00	41,791	83	2	15	15	0	Do.
28	2.00	18,015	36	2½	10	10	0	Do.
33	2.00	44,000	88	2	8	2	6	Old house, very full of cracks.
34	2.00			3	15	14	1	Large house, well papered.
35	2.00	18,000	36	2	20	17	3	Old house, well papered.
39	2.00	14,000	28	12	15	14	1	Tight house.
45	3.00	24,350	73	1½	16	14	2	Large house, separate rooms papered.
57	3.00	17,350	51	3	15	15	0	Tight house.
58	3.00	17,000	51	3	15	7	8	Old house; insects on top floor alive, others dead.
61	3.00	26,340	79	3	10	8	2	Tight house.
64	3.00			3	15	13	2	Old house, well papered.
70	3.00	23,900	70	2½	20	8	12	Hotel, well papered.
18	2.00	14,112	28	2	20	20	0	Tight house; 2 dead rats.
27	2.00	14,112	28	3	13	13	0	Tight house; same house in rest of this series.
30	2.00	14,112	28	2	13	13	0	Tight house; strong wind.
32	2.00	14,112	28	2½	13	13	0	Tight house.
36	2.00	14,112	28	2	13	12	1	Tight house; strong wind; insect on windward side alive.
42	2.00	14,112	28	2½	13	12	1	Tight house; 12 pots, 2½ pounds per pot.
46	2.00	14,112	28	2½	13	12	1	Tight house; 14 pots, 2 pounds per pot.
48	2.00	14,112	28	2½	13	13	0	Do.
59	2.00	14,112	28	3	13	13	0	Tight house; 7 pots, 4 pounds per pot.
60	2.00	14,112	28	2½	13	13	0	Tight house; 28 pots, 1 pound per pot.
65	2.00	14,112	28	3	13	13	0	Tight house; 7 pots, 4 pounds per pot; 12 rats killed.
66	1.50	14,112	21	2½	13	13	0	Tight house; 7 pots, 3 pounds per pot; 9 rats killed.
67	1.00	14,112	14	2½	13	7	6	Tight house; 14 pots, 1 pound per pot.
68	1.00	14,112	14	2	13	10	3	Tight house; 7 pots, 2 pounds per pot.
71	1.50	14,112	21	3½	13	13	0	Tight house; 7 pots, 3 pounds per pot.
72	1.50	14,112	21	2½	13	13	0	Tight house; 21 pots, 1 pound per pot.
73	1.00	14,112	14	2½	13	13	0	Tight house; 14 pots, 1 pound per pot; high wind.
75	2.00	14,112	28	3	90	90	0	Tight house; 14 pots, 2 pounds per pot.
77	2.00	14,112	28	3	13	13	0	Do.
80	1.00	14,112	14	2	13	13	0	Tight house; 14 pots, 1 pound per pot.
81	.75	14,112	11	2	13	13	0	Tight house; 4 pots, 2½ pounds per pot.
83	.75	14,112	11	2	13	13	0	Tight house; 8 pots, 1½ pounds per pot.
85	.75	14,112	11	2	13	13	0	Do.
87	.75	14,112	11	2	13	13	0	Tight house; 4 pots, 2½ pounds per pot.
91	.75	14,112	11	2	13	13	0	Tight house; 2 pots, 5½ pounds per pot.
94	.75	14,112	11	1½	13	13	0	Tight house; 8 pots, 1½ pounds per pot.
96	.75	14,112	11	1½	13	13	0	Tight house; 4 pots, 2½ pounds per pot.
98	.75	14,112	11	1½	13	13	0	Tight house; 2 pots, 5½ pounds per pot.
100	.75	14,112	11	1½	11	11	0	Tight house; 4 pots, 2½ pounds per pot.
102	.75	14,112	11	1½	13	13	0	Do.
104	.50	14,112	7	1½	13	13	0	Tight house; 7 pots, 1 pound per pot.
107	.50	14,112	7	1	13	13	0	Do.
109	.75	14,112	11	1	13	13	0	Tight house; 7 pots, 1½ pounds per pot.
113	.75	14,112	11	1	13	12	1	Do.
116	1.00	14,112	14	2	13	13	0	Tight house; 7 pots, 2 pounds per pot.
120	1.00	14,112	14	2	13	13	0	Tight house; 14 pots, 1 pound per pot.
122	1.00	14,112	14	2	13	13	0	Tight house; 7 pots, 2 pounds per pot.
125	1.00	14,112	14	2	13	13	0	Do.

TABLE II.—*Pyrethrum.*

Experiment No.	Fumigant used per 1,000 cubic feet.	Area fumigated.	Fumigant used.	Time.	Mosquitoes.			Remarks.
					Number.	Dead.	Alive.	
	Lbs.	Cu. ft.	Lbs.	Hrs.				
8	3			3	40	14	26	Large building, well papered and tight.
15	2	34,794	69	3	10	3	7	Insects on ground floor only killed.
20	2			3	10	10	0	Very favorable house, very tightly closed.
22	2			3	20	13	7	Large building, well papered and tight.
23	2	37,500	75	2	10	0	10	Old building, but well papered.
29	2	20,000	40	2	15	10	5	Old building, fairly well closed.
40	2	31,000	63	2½	20	16	4	New building, well closed.
41	2	25,000	51	2½	20	8	12	Old building, full of cracks.
44	3	28,960	87	1½	20	0	20	New house, no false ceiling, wind removed fumes.
54	3			3	20	0	0	Insects stupefied, dead in 24 hours.
62	3			3½	9	8	1	Excellent house, well papered, fumes very dense.
64	3			2½	13	11	2	Sulfur used in other part of this house.
21	2	14,112	28	2	21	13	8	House well papered, moderate breeze, no leakage.
25	3	14,112	42	2½	40	32	8	Remaining experiments carried on in this house.
26	3	14,112	42	3	13	9	4	14 pots used, 3 pounds per pot.
30	3	14,112	42	3½	13	13	0	Do.
31	3	14,112	42	3	13	7	6	Do.
37	3	14,112	42	2½	13	0	13	14 pots used, 3 pounds per pot, old pyrethrum from open barrel.
38	3	14,112	42	2	13	12	1	28 pots, 1½ pounds per pot.
43	3	14,112	42	2½	13	4	9	Do.
47	3	14,112	42	2½	13	2	11	Do.
49	3	14,112	42	2½	13	7	6	Do.
50	3	14,112	42	2½	13	5	8	7 pots, 6 pounds per pot.
51	3	14,112	42	2½	13	4	9	28 pots, 1½ pounds per pot.
52	3	14,112	42	3½	13	13	0	7 pots, 6 pounds per pot.
53	2	14,112	28	2½	13	11	2	14 pots, 2 pounds per pot.
55	2	14,112	28	3½	13	9	4	7 pots, 4 pounds per pot.
56	2	14,112	28	2½	13	6	7	28 pots, 1 pound per pot.
105	3	14,112	42	3	13	13	0	4 pots, 7 pounds per pot.
108	3	14,112	42	3	13	12	1	7 pots, 4 pounds per pot.
110	3	14,112	42	3	13	12	1	Do.
114	3	14,112	42	3	13	11	2	Do.
117	3	14,112	42	3	13	12	1	Do.
119	3	14,112	42	3	13	11	2	Do.
123	3	14,112	42	3	13	11	2	Do.
126	3	14,112	42	3	13	10	3	Do.

TABLE III.—*Campho-phenique.*

Experiment No.	Fumigant used per 1,000 cubic feet.	Area fumigated.	Mixture used.	Time.	Mosquitoes.			Remarks.
					Number.	Dead.	Alive.	
	Ozs.	Cu. ft.	Ozs.	Hrs.				
89	4	3,746	15	1	12	12	0	Room in a house; habitable one hour after opening.
69	4	14,112	56	1	10	9	1	House well papered; moderate breeze; old pots.
74	4	14,112	56	3	13	8	5	Do.
76	4	14,112	56	3	9	9	0	House well papered, and new pots used in all remaining experiments.
78	4	14,112	56	3	9	9	0	
79	4	14,112	56	3	9	9	0	
82	4	14,112	56	2	9	9	0	
84	4	14,112	56	1.50	9	9	0	
86	4	14,112	56	1.50	9	9	0	
88	4	14,112	56	1.50	9	9	0	
90	4	14,112	56	1.50	9	9	0	
92	4	14,112	56	1	9	9	0	
93	4	14,112	56	1	9	9	0	
95	4	14,112	56	.75	9	9	0	
97	4	14,112	56	.75	9	9	0	
99	4	14,112	56	.75	9	7	2	
101	4	14,112	56	.75	9	8	1	
103	4	14,112	56	1	9	9	0	
106	4	14,112	56	1	9	9	0	
111	4	14,112	56	1	9	9	0	
112	4	14,112	56	1	9	9	0	
115	4	14,112	56	1	9	9	0	
118	4	14,112	56	1	9	9	0	
121	4	14,112	56	1	9	9	0	
124	4	14,112	56	1	9	9	0	

In these comparisons one experiment was done each day, using varying amounts of the culicides, as shown below. Three houses, each containing 14,112 cubic feet, papered as nearly as possible alike, with the same exposure, and with the same internal arrangements, were used for this purpose. The physical exposures also were identical. The object of this work was to show the relative values of the three fumigants when tested under exactly the same conditions.

TABLE IV.—Comparison of pyrethrum, sulfur, and campho-phenique.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Pyrethrum:											
Quantity per 1,000 cubic feet.....pounds..	3	3	3	3	3	3	3	3	3	3	3
Quantity used.....do....	42	42	42	42	42	42	42	42	42	42	42
Time.....hours..	3	3	3	3	3	3	3	3	3	3	3
Mosquitoes.....number..	15	15	15	15	15	15	15	15	15	15	15
Dead.....do....	10	14	11	9	12	13	13	12	14	14	15
Alive.....do....	5	1	4	6	3	2	2	3	1	1	0
Sulfur:											
Quantity per 1,000 cubic feet.....pounds..	3	3	2	2	2	2	2	1	1	1	1
Quantity used.....do....	42	42	28	28	28	28	28	14	14	14	14
Time.....hours..	3	3	3	2	2	2	1	1	2	2	2
Mosquitoes.....number..	15	15	15	15	15	15	15	15	15	15	15
Dead.....do....	15	15	15	15	15	15	15	15	15	15	15
Alive.....do....	0	0	0	0	0	0	0	0	0	0	0
Campho-phenique:											
Quantity per 1,000 cubic feet.....ounces..	4	4	4	4	4	4	4	4	4	4	4
Quantity used.....do....	56	56	56	56	56	56	56	56	56	56	56
Time.....hours..	3	3	3	2	2	2	1	1	1	1	1
Mosquitoes.....number..	15	15	15	15	15	15	15	15	15	15	15
Dead.....do....	15	15	15	15	15	15	15	15	15	15	15
Alive.....do....	0	0	0	0	0	0	0	0	0	0	0

By the term "mosquitoes used" is meant the number of cages used. More than eight insects are placed in a cage. If all the insects in a cage are dead, it is so recorded; if one or more are alive, the record "alive" is used. This explanation holds for all similar results in this paper.

TABLE V.—Action of sulfur, pyrethrum, and campho-phenique on fruit.

[D., darkened, referring to the skins. Interior unchanged. S. d., slightly darkened. Interior unchanged. O. K., apparently unchanged. Taste, distinct characteristic taste of the fumigant in the interior of the fruit. Sticky, the skin of the fruit is sticky. Interior unchanged. All observations made after 24 hours.]

Fumigant.	Time.	Mosquitoes.			Bananas.	Mangoes.	Oranges.	Quantity per 1,000 feet.
		Num-ber.	Live.	Dead.				
<i>First experiment.</i>								
Sulfur.....	2	17	4	13	D.....	O. K.....	O. K.....	Pounds. 2
Pyrethrum.....	3	17	8	9	D.....	Taste.....	Taste.....	3
Campho-phenique.....	1	17	a1	16	S. d.....	O. K.....	O. K.....	b4
<i>Second experiment.</i>								
Sulfur.....	2	17	0	17	D.....	Sticky.....	O. K.....	2
Pyrethrum.....	3	17	9	8	D.....	Taste.....	Taste.....	3
Campho-phenique.....	1	17	0	17	D.....	Sticky.....	Taste.....	b4

a Died inside of thirty minutes after fumigating.

b Ounces.

Mice and rats placed in the campho-phenique survive about twenty-four hours; at the end of that time they die rather suddenly, with slightly reddened urine and intense congestion of the kidneys, simulating macroscopically acute hemorrhagic nephritis.

Since the body of this paper was written, a number of experiments have been made to determine the bacterial efficiency of campho-phenique. The organism chosen for this work was *Bacillus subtilis*,

an organism whose resistance is about the same as that of *Bacillus anthracis*, or more correctly *Bacterium anthracis*. The bacteria were obtained from a hay infusion; they were allowed to grow, after being purified, until numerous spores were present in each filament, then placed upon glass rods, which had previously been sterilized, and dried, while suspended in sterile glass tubes. After drying over night they were placed in appropriate positions in the houses previous to lighting the lamps and subjected to the regular fumigation process. After the fumigation was ended they were washed with sterile water twice, to remove whatever carbolic acid might have adhered to them, and incubated in bouillon tubes. At the end of two days they were examined for growth. Typhoid bacilli also were used. The latter organism represents more closely the resistance one would meet with in ordinary bacterial fumigations. They were prepared and treated in precisely the same manner.

After a few preliminary experiments it was found that better results could be obtained by the addition of formaldehyde to the campho-phenique. While the campho-phenique had a decided bactericidal action, the camphor-carbolic acid-formaldehyde mixture was much better.

Koch has found that it takes about two hours to kill *Bacterium anthracis* with 5 per cent carbolic acid alone, hence our results, representing as they do a very resistant type of organism, seem to show that the mixture referred to above is not only an excellent culicide, but a very powerful bactericide.

The table below shows the results obtained.

Experiment No.	Fumigant.	Time.	Mixture per 1,000 cubic feet.	Result.
		Hours.	Ounces.	
1	Campho-phenique	1	4	3 out of 17 dead. ^a
2	do.....	1	4	7 out of 21 dead. ^a
3	do.....	1	4	6 out of 18 dead. ^a
4	Campho-phenique, formaldehyde		2	16 dead, 4 live. ^a
				20 dead, 0 live. ^b
5	do.....		2	17 dead, 3 live. ^a
				22 dead, 0 live. ^b

^a *Bacillus subtilis*.

^b *Bacillus typhesus*.

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